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(71) Applicant (for all designated States except US): **BRITISH NUCLEAR FUELS PLC** [GB/GB]; Sellafield R & T North, B141 Sellafield, Seascale, Cumbria CA20 1PG (GB).

(72) Inventors; and

(75) Inventors/Applicants (for US only): **LAMBERT, John** [GB/GB]; BNFL Field Services, Berkeley Centre, Berkeley

Glos. GL13 9PB (GB). **JARRETT, Eric** [GB/GB]; BNFL Field Services, Berkeley Centre, Berkeley Glos. GL13 9PB (GB).

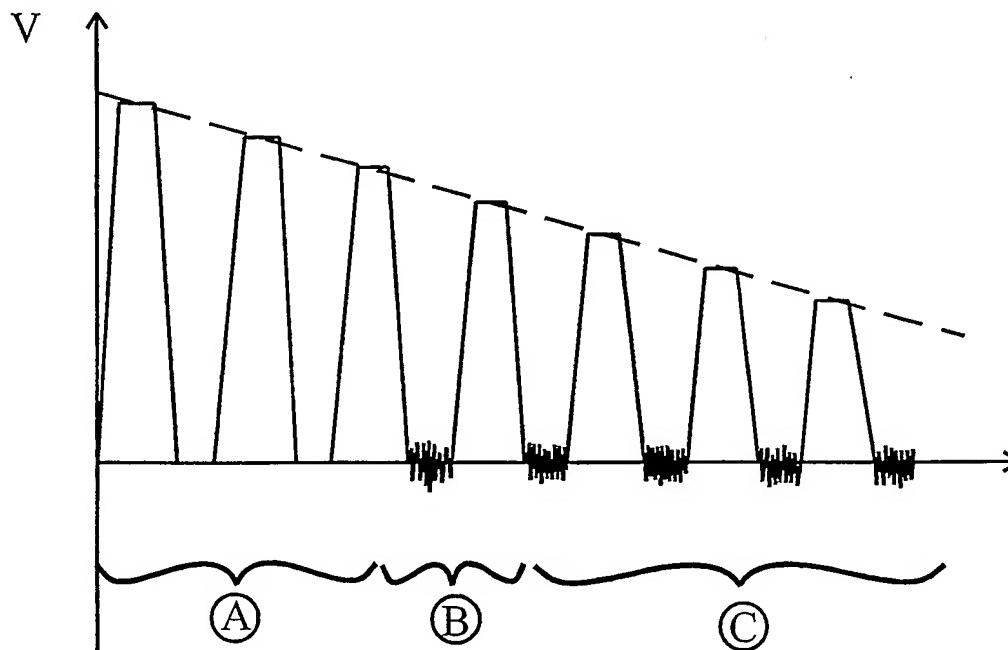
(74) Agent: **HARRISON GODDARD FOOTE**; Belgrave Hall, Belgrave Street, Leeds LS2 8DD (GB).

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[Continued on next page]

(54) Title: **WELDING QUALITY CONTROL**



(57) Abstract: Apparatus and method for controlling weld conditions during welding by identifying a transition (B) between a first mode of operation (A) during which no spatter is produced, and a second mode of operation during which a minimal amount of spatter is produced; and adjusting a power supply voltage (Vs) whereby welding occurs under conditions associated with said transition (B); and whereby said step of identifying said transition comprises identifying near zero voltage fluctuations in said power supply voltage (Vs).



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For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

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WELDING QUALITY CONTROL

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5 The present invention relates to a method and apparatus for providing predetermined welding conditions during a welding process. In particular, but not exclusively, the present invention relates to a method and apparatus for adjusting a power supply voltage supplied to an electrode in a Gas Metal Arc Welding (GMAW) process.

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Various welding processes are known in the prior art for forming a weld at a metal weld target. One such process is metal inert gas (MIG) welding another is metal-arc active gas (MAG) welding. Both of these are forms of gas metal arc welding (GMAW). In such a welding process a feed wire electrode is provided which is connected to a power supply. When the electrode is powered an electrical arc is produced between the electrode and the work target to be welded. An inert gas is provided in the region around the arc. As welding occurs the electrode is fed towards the work target and is consumed by melting under the intense heat produced by the arc. The metal of the electrode is deposited on the work target forming the weld.

25

There are two different types of (GMAW)-welding processes. These are conventional GMAW and pulsed GMAW. Pulsed GMAW welding uses a pulsed current (Typically 400A to 50A and 40Hz and 100Hz) to produce an arc gap between wire tip and the work through which droplets of superheated metal (typically the diameter of the welding wire) are propelled into the weld pool. Transfer of droplets occurs through the arc typically one droplet per pulse.

There are problems associated with welding techniques in the prior art. One problem is to control the size and shape of the metal puddle at the work target. If the puddle becomes too large gravitational components can cause undue flowing of the molten metal in the puddle. If current density reaches a value which is not sufficient to expel the metal from the end of the electrode the metal droplets which form increase in size until its mass and gravity causes it to break loose and fall towards the puddle. When droplets impact with the molten puddle in a dropping process molten metal will splash around the weld zone. This results in spattering surrounding the work and can result in a poor quality weld. Weld spatter may also be caused when the welding engineer sets the preset voltage too low often caused by welding conditions changing after laboratory test welds. When this happens the wire tip strikes the work, welding current momentarily rapidly increases, voltage short circuits and metal droplets are flung out of the pool causing spatter.

Another particular problem is poor bead shape. This is caused by long arc lengths caused by setting the power supply voltage too high. Poor bead shape can lead to poor weld strength and other problems.

In certain environments the quality of a weld and effects caused by the welding process can be critical. For example use of pulsed (GMAW) welding for conducting repairs in nuclear reactors has been used for many years. However the existence of spatter in such circumstances could, it has been argued, affect the integrity of fuel elements in the reactor. For this reason special safe guards are taken when welding in such environments. In order to prevent falling spatter "umbrellas" and welding

package spatter guards are used. However their deployment is time consuming and not always completely effective in eliminating spatter. Whilst studies have shown that falling spatter does not in fact significantly effect the integrity of reactor internals it would clearly be
5 advantageous to control the production of spatter during a welding process as spatter formation is an indication of inferior weld quality and of damaging welding equipment.

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In the past such control has been possible by using a highly skilled welding engineer who, using an arc screen, has been able to view the arc at the beginning of a welding process and manually adjust various parameters
15 of the welding process such as power supply settings. Through experience the engineer can select settings to produce welds with a reduced level of spatter, good fusion characteristics and a good bead shape. However in order to produce these good welding characteristics a
20 skilled welding engineer must be on site to observe each weld as it is initiated. This can be an expensive and time consuming process.

Furthermore even for a single weld procedure optimum
25 power supply voltage settings may vary over a considerable range during welding. This may be caused by variations in the quality of earth connection, environmental temperature and other factors. As a result unless a welding engineer continues to supervise or carry
30 out the welding the weld can progress with less than optimum characteristics.

Still further problems with the welding process occur in remote welding situations in which an engineer
35 must observe the welding process remotely. This can

occur when it is not possible for a human to access the weld point.

It is an aim of embodiments of the present invention
5 to at least partly mitigate the above-mentioned problems.

According to a first aspect of the present invention there is provided a method of welding comprising the steps of:

10 during welding, identifying a transition between a first mode of operation during which no spatter is produced, and a second mode of operation during which a minimal amount of spatter is produced; and

adjusting a power supply voltage whereby welding
15 occurs under conditions associated with said transition; whereby

said step of identifying said transition comprises identifying near zero voltage fluctuations in said power supply voltage.

20

According to a second aspect of the present invention there is provided a method of welding comprising the steps of:

during a welding process, identifying near zero
25 voltage fluctuations in a power supply voltage; and

responsive to the detection of said fluctuations adjusting said power supply voltage.

According to a third aspect of the present invention
30 there is provided welding apparatus for providing predetermined weld conditions during a welding process comprising:

a main electrode for forming molten metal and an arc between the electrode and a work target;

a power supply arranged to supply a power supply voltage to said electrode;

means for identifying a transition, during welding, between a first mode of operation and a second mode of operation; and

means for adjusting the power supply voltage whereby welding occurs under conditions associated with said transition; wherein said means for identifying a transition comprises means for identifying near zero voltage fluctuations in the power supply.

Embodiments of the present invention provide the advantage that optimum working point conditions in respect of both spatter and weld quality can be maintained at all times during a weld process. The voltage power supply may be controlled automatically so that the voltage supplied to the electrode is neither so high that a poor bead shape is obtained nor too low that poor fusion occurs.

20

Embodiments of the present invention provide the advantage that predetermined weld conditions may be provided by welding apparatus without any necessity for human intervention. This reduces the cost and also makes the welding process less prone to human error.

Embodiments of the present invention provide the advantage that welding occurs under conditions associated with a transitional point between a mode of operation in which voltage power supply is too high and voltage power supply is too low. Automatic adjustments so that welding occurs in this transitional region ensures that regardless of any variation in environmental factor during welding the optimum power supply voltage is used at all times thereby keeping the production of spatter to

30

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a minimum whilst providing best quality welding and bead shape.

Embodiments of the present invention will now be
5 described hereinafter, by way of example only, with reference to the accompanying drawings in which:

Figure 1 illustrates a welding process;

Figure 2 illustrates drop formation and spatter;

10 Figure 3 illustrates bead shapes;

Figure 4 illustrates a pulsed supply;

Figure 5 illustrates the onset of near zero voltage fluctuations; and

Figure 6 illustrates circuitry which may be used to
15 control power supplied to welding apparatus.

In the drawings like reference numerals refer to like parts.

20 Figure 1 illustrates a welding process. In particular figure 1 illustrates a gas metal arc welding (GMAW) process. A metal work piece 10 (which acts as a target piece) is welded by virtue of gas nozzle 11. The gas nozzle includes an outer sheath 12 which surrounds an
25 inner contact tube 13 which itself surrounds a consumable electrode 14. An inert gas is continually discharged in the direction of arrows A towards the work piece 10. The shielding gas 15 performs a number of functions such as helping to form the arc plasma, stabilising the arc
30 routes on the material surface and ensuring a smooth transfer of molten droplets as the electrode end melts. The arc 16 is formed between the metal electrode 14 and the work piece 10. The arc produces heat which melts the tip of the electrode and ensures that a molten weld pool
35 17 is maintained. As the welding nozzle 11 moves along

the work piece 10, illustrated by the direction of arrow B in figure 1 the molten metal forms weld metal 18.

Figure 2 illustrates a welding process under conditions whereby spatter occurs. In accordance with a normal pulsed MIG process droplets of molten metal formed from melted electrode form at the electrode tip 20. Under certain circumstances the drops 21 are not caused to flow into the molten pool 17 before the gravitational forces on those drops cause the drops to fall. Under these conditions when the drops hit the surface of the molten pool further droplets 22 are caused to splash around the weld zone. These subsequently fall onto the surface of the metal where they solidify. These drops 22 form spatter. Spatter may also occur when the wire tip touches the work site which causes a short circuit and then a droplet being expelled from the weld pool. Embodiments of the present invention provide a way in which the production and distribution of the spatter droplets may be controlled. Embodiments of the present invention also provide a way in which the bead shape of the welded metal 18 may be controlled. Figure 3a illustrates a poor bead shape including steep sided end portions 31 and an uneven surface 32. A poor bead shape may also include a relatively high bead height to bead width ratio of for example 0.43. Figure 3b illustrates a more optimum bead shape having a relatively smooth profile and a bead height to bead width ratio of around 0.34. It will be appreciated by those skilled in the art that the bead shape is indicative of weld quality with a good bead shape being synonymous with a good weld quality. When the power supply voltage supplied to the electrode 14 is set too high (for example 41 volts) no spatter is produced. However the bead shape is poor with a relatively high bead height to bead width ratio. This

type of (humpy) bead shape makes it very difficult to produce good quality multi-pass deposits and may cause defects such as inclusions and lack of fusion in the metal. However when the power supply voltage is set too low (for example 32 volts) continuous large spatter droplets are produced. It is noted that bead shape under these low voltage conditions is satisfactory but a poor base plate fusion occurs. The optimum power supply voltage setting (for example 37.5 volts) occurs at a transitional point between no spatter and only occasional spatter droplet formation. Under these conditions bead shape is excellent, good base plate fusion occurs and spatter generation is kept to a minimum. This optimum working point condition occurs at the onset of near zero voltage fluctuations in the power supply to the electrode 14.

Figure 4 illustrates how the voltage power supply to the electrode 14 is pulsed during a welding process. A supply voltage V_S is selected. This sets a peak voltage which may be applied to the electrode 14. This voltage is pulsed as illustrated in figure 4 so that as droplets form on the end of the electrode a predetermined amount of current is added to push that droplet across the arc and into the molten puddle. By pulsing the current at times only when a droplet is ready at the end of the electrode extra power is not needed when a droplet is not correctly formed. By reducing overall power supplied using pulsing cooling off periods between molten droplet deposition are provided. This enables welding to be used on relatively thin metal material to control distortion and to avoid wastage of electrode 14. It will be understood that embodiments of the present invention are not limited to use with such thin target material.

The optimum power supply voltage VS which may be selected varies over a considerable range depending upon specific weld set up conditions. For example in remote welding a main cause of this variation is the quality of earth connection available where the weld is to be carried out. This earth connection may itself be required to be connected remotely. As the earth connection improves (which may occur at different welding locations or even during a single welding operation), the power supply voltage requires to be reduced to maintain an optimum condition. If the earth connection degrades the supply voltage may require increasing. Other variations of factors during welding may also effect the level of optimum power supply voltage. Also optimum power supply voltage setting often needs to be changed for mechanised non-remote welding for similar reasons and also where burn-off changes occur. Burn-off relates to how much welding wire is being consumed. Thus high burn off occurs when the power supply parameters are set to give high melting rates i.e. high peak currents, short background current times etc. The optimum welding condition is when burn off rate equal wire feed speed then the arc length (gap) remains constant. For these and other reasons it will be understood that an optimum power supply voltage may not remain "optimum" throughout the duration of the welding operation.

By way of example figure 5 illustrates how weld conditions may vary as the voltage supply is intentionally decreased. During a first high voltage zone, indicated by area A, the power supply voltage is too high. Although no spatter will occur in this area together with good fusion characteristics a poor bead shape is obtained. Region B indicates an optimum condition region where there is only intermittent very

fine spatter of a very limited amount with good bead shape and good fusion. When the power supply voltage setting is too low indicated by region C a large amount of spatter droplets and poor fusion are produced. It will be noticed that as the power supply voltage setting is decreased from the first mode of operation in region A to a second mode of operation in region B a transition occurs and an onset of near zero voltage fluctuations occur. By observing the onset of these near zero voltage fluctuations one can determine that an optimum power supply voltage setting for the environmental conditions where the welding process is to take place, have been attained. Embodiments of the present invention identify the occurrence and frequency of these near zero voltage fluctuations and then automatically adjust the power supply so that the optimum spatter condition is obtained throughout the welding period. This automatic adjustment allows the optimum conditions to be reached without constant surveillance by a skilled welding engineer and also allows for on-line adjustment should burn-off characteristics change during welding. Burn-off characteristics are conditions which can affect the melting rate of the wire, i.e. some wires for the same welding parameters may burn back (melt) differently. Such conditions are material variations affecting contact tip performance, conduction, boiling vaporisation etc.

Figure 6 illustrates circuitry which can identify the onset of these near zero voltage fluctuations from the normal pulsed voltage fluctuations of the power supply source of welding apparatus. The circuitry also produces an output which can be used to control the power supply voltage to ensure good working conditions are maintained. It will be understood that embodiments of the present invention are not limited to any particular

form of circuitry which can enable the onset to be detected. The weld voltage input V_{in} , which is the power supply voltage applied to the electrode, is applied to the inverting input of comparator 60 via a potential divider arrangement provide by resistors 61 and 62. The
5 remaining input to the comparator 60 has a fixed voltage V_{ref} set by variable potentiometer formed by resistors 63 and 64. By selecting the fixed voltage V_{ref} the comparator output is made to change state when the weld
10 input voltage approaches zero. Resistors 65 and 66 set the hysteresis of the comparator. The output of the comparator is connected to node 67 and is input into monostable 68. The output of this monostable provides a 50% duty cycle derived from the negative transition of
15 the comparators output. This signal feeds a charge pump circuit formed by resistor 69, diode 70 and capacitor 71. Resistor 72 provides a discharge path. The resultant DC voltage on capacitor 71 is buffered by operational amplifier 72 and fed to a summing amplifier 73. This
20 voltage is then amplified with a gain of -0.25 and added to a set weld voltage derived from a variable potentiometer 74. This preset weld voltage may be selected at the beginning of a welding process by an operator. The output of the summing amplifier 73 may be
25 then used to combine with the set voltage in the welding power supply.

It will be understood that embodiments of the present invention provide an electronic controller which
30 detects voltage variations which indicate the occurrence of spatter during a welding process. The controller automatically adjusts the welding power supply parameters so that all but the "occasional" spatter droplet is formed. This condition coincides with the deposition of
35 a GMAW weld deposit with optimum fusion properties and

bead shape characteristics. The controller determines the onset of spatter by using pulse height discrimination techniques. In particular the detection of near zero pulses. The resultant pulses are stretched in order to
5 ensure a constant pulse width is obtained independent of the size of the input pulse. The integration of this measurement will produce a low frequency signal that if combined with the initial power supply settings will allow automatic adjustment of the settings to produce the
10 optimal spatter characteristics.

Embodiments of the present invention provide the advantage that no welding engineer is required for a preliminary set-up. Voltage power supply is controlled
15 continually to adjust settings so as to optimise welding no matter what burn-off condition prevails. Embodiments of the present invention may be used in conjunction with an ESAB ARISTO 400 pulsed MIG welding power supply. This may be used in remote reactor repairs. These may be
20 particularly made in Magnox power stations. It will be understood that the present invention is not restricted to use in such environments. Likewise it will be understood that embodiments of the present invention may be used in various types of welding processes. For
25 example conventional MIG or MAG, low current short circuit MIG/MAG welding (as used for thin sheet welding typical when welding car bodies) and/or submerged arc welding.

30 Embodiments of the present invention provide an electronic control system which may be interfaced with the arc voltage signal and power supply pendent to produce on-line corrections to operate at the optimum welding condition during a welding process.

35

It will be understood that a preferred embodiment of the present invention has been described hereinabove. It will likewise be understood that the present invention is not restricted to use in such an example but rather
5 modifications and variations may be made without departing from the scope of the present invention.

CLAIMS:

1. A method of welding comprising the steps of:
during welding, identifying a transition between a
5 first mode of operation during which no spatter is produced, and a second mode of operation during which a minimal amount of spatter is produced; and
adjusting a power supply voltage whereby welding occurs under conditions associated with said transition;
10 whereby
said step of identifying said transition comprises identifying near zero voltage fluctuations in said power supply voltage.
- 15 2. The method as claimed in claim 1 further comprising automatically adjusting said power supply voltage.
3. The method as claimed in any one of claims 1 or claim 2 further comprising continually adjusting said
20 power supply voltage.
4. The method as claimed in any one of claims 1 to 3 further comprising performing a whole welding process under said conditions.
- 25 5. The method as claimed in any one of claims 1 to 4 further comprising the steps of;
monitoring near zero power supply voltage signals during welding; and
30 determining when an onset of near zero voltage fluctuations occurs said onset indicating a transition from said first to said second mode of operation.

6. The method as claimed in any one of claims 1 to 5 comprising a method of pulsed metal inert gas (MIG) welding.

5 7. A method of welding comprising the steps of:
during a welding process, identifying near zero voltage fluctuations in a power supply voltage; and
responsive to the detection of said fluctuations adjusting said power supply voltage.

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8. The method as claimed in claim 7 further comprising automatically adjusting said power supply voltage.

9. The method as claimed in claim 7 or claim 8 further
15 comprising continually adjusting said power supply voltage.

10. The method as claimed in any one of claims 7 to 9 further comprising:

20 during welding adjusting power supply voltage responsive to variations in weld set up conditions.

11. The method as claimed in any one of claims 7 to 10 comprising a method of pulsed metal inert gas (MIG)
25 welding.

12. Welding apparatus for providing predetermined weld conditions during a welding process comprising:

30 a main electrode for forming molten metal and an arc between the electrode and a work target;

a power supply arranged to supply a power supply voltage to said electrode;

means for identifying a transition, during welding, between a first mode of operation and a second mode of
35 operation; and

means for adjusting the power supply voltage whereby welding occurs under conditions associated with said transition; wherein said means for identifying a transition comprises means for identifying near zero
5 voltage fluctuations in the power supply.

13. Apparatus constructed and arranged substantially as hereinbefore described with reference to the accompanying drawings.

10

14. A method substantially as hereinbefore described with reference to the accompanying drawings.

15

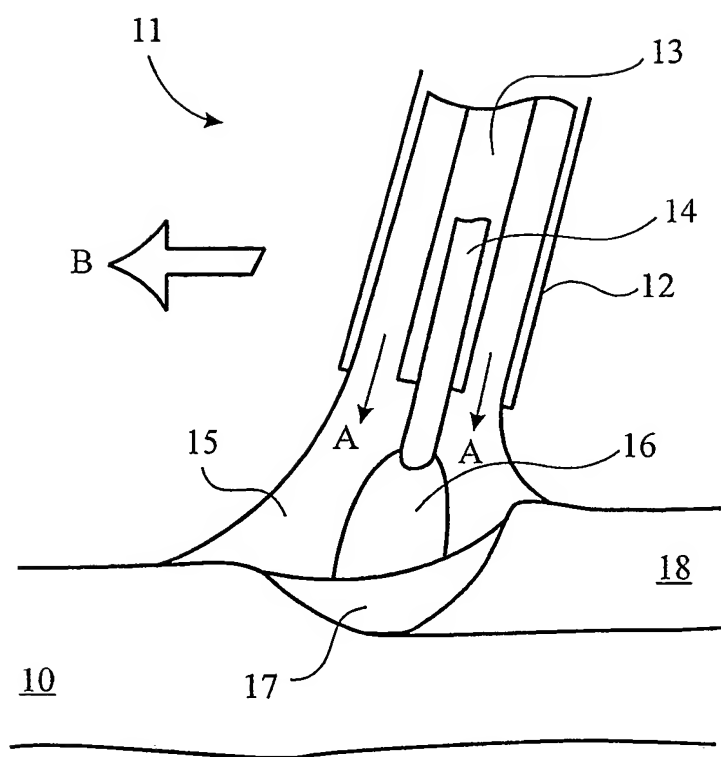


Fig. 1

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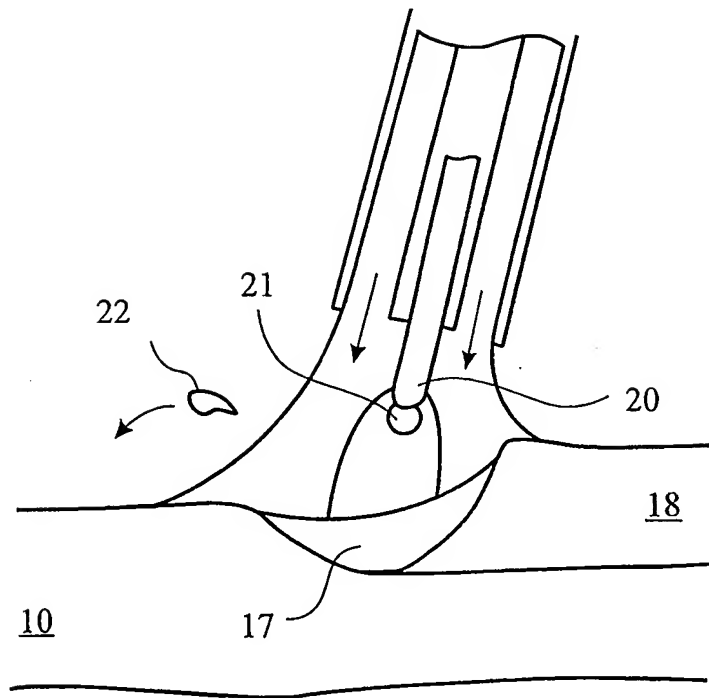


Fig. 2

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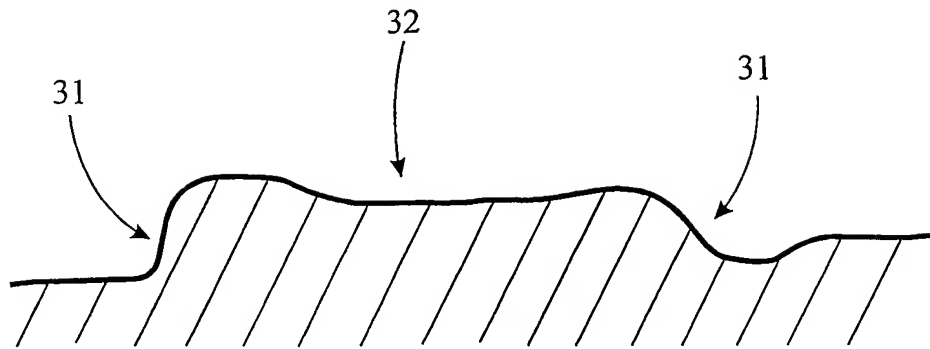


Fig. 3A

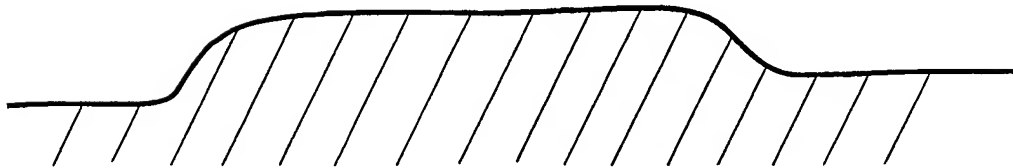


Fig. 3B

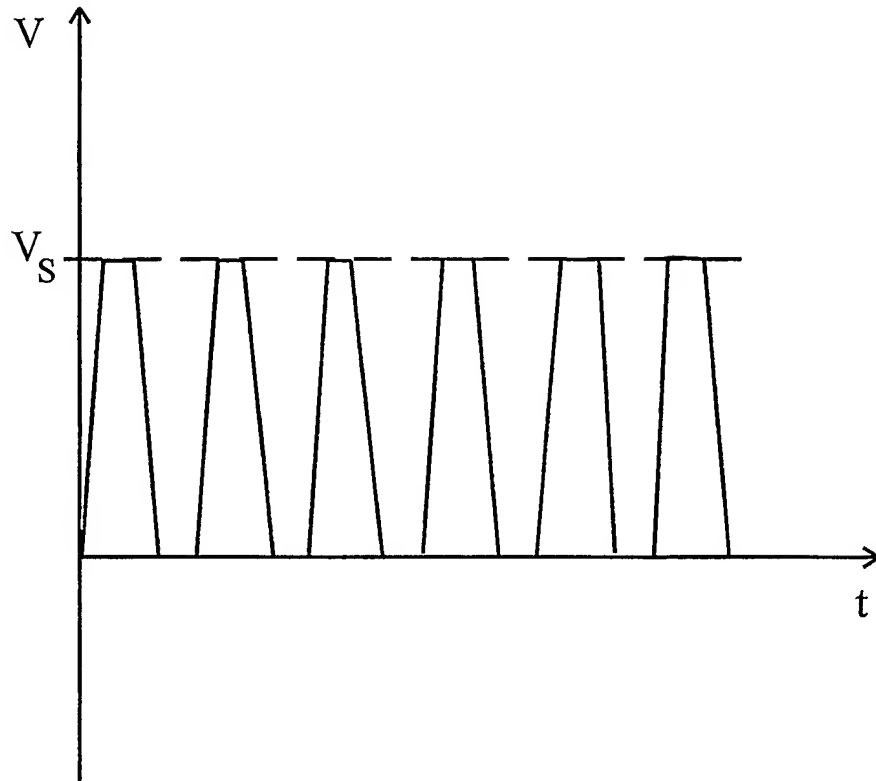


Fig. 4

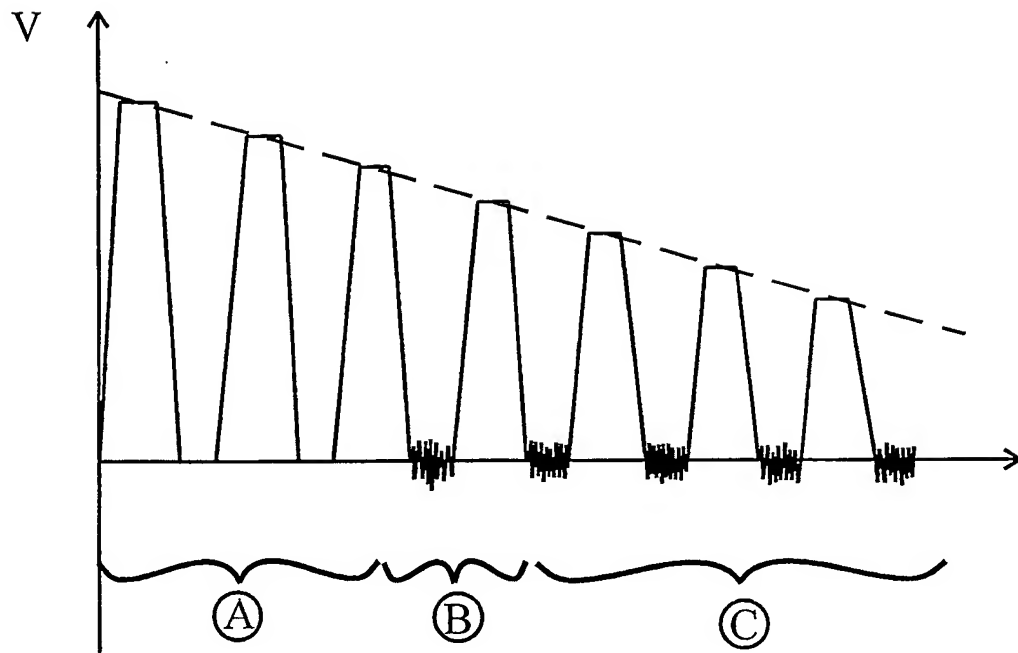


Fig. 5

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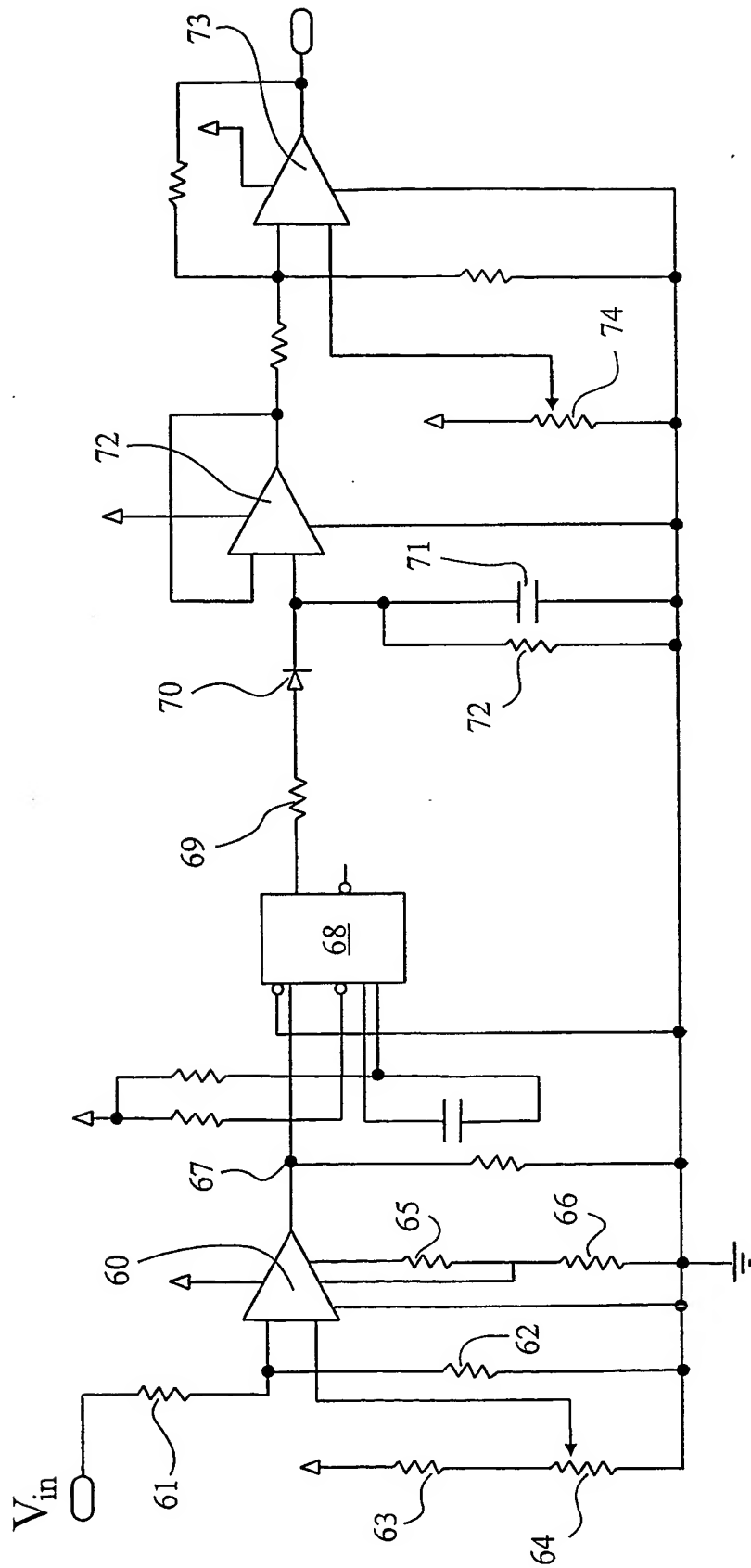


Fig. 6

INTERNATIONAL SEARCH REPORT

Int nal Application No
PCT/GB2004/000117

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 B23K9/09 B23K9/095

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 B23K

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data, PAJ

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2002/008095 A1 (DEAN GARY ET AL) 24 January 2002 (2002-01-24) page 3, paragraph 49 -page 4, paragraph 62; figures 2,4	1,12
A	EP 0 787 555 A (MATSUSHITA ELECTRIC IND CO LTD) 6 August 1997 (1997-08-06) claims 1,22; figures 3,5,7,10,14,19,20	1,12
A	EP 1 252 962 A (CENTRAL MOTOR WHEEL CO LTD) 30 October 2002 (2002-10-30) claim 1; figures 1,7-9,14	1,12

☐ Further documents are listed in the continuation of box C.

☒ Patent family members are listed in annex.

* Special categories of cited documents:

- *A* document defining the general state of the art which is not considered to be of particular relevance
- *E* earlier document but published on or after the international filing date
- *L* document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
- *O* document referring to an oral disclosure, use, exhibition or other means
- *P* document published prior to the international filing date but later than the priority date claimed

- *T* later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
- *X* document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
- *Y* document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.
- *Z* document member of the same patent family

Date of the actual completion of the international search

19 May 2004

Date of mailing of the international search report

28/05/2004

Name and mailing address of the ISA

European Patent Office, P.B. 5818 Patentlaan 2
NL - 2280 HV Rijswijk
Tel. (+31-70) 340-2040, Tx. 31 651 epo nl,
Fax: (+31-70) 340-3016

Authorized officer

Concannon, B

INTERNATIONAL SEARCH REPORT

.....tional application No.
PCT/GB2004/000117

Box II Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This International Search Report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:
2. ☒ Claims Nos.: 13, 14
because they relate to parts of the International Application that do not comply with the prescribed requirements to such an extent that no meaningful International Search can be carried out, specifically:
see FURTHER INFORMATION sheet PCT/ISA/210
3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box III Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this International application, as follows:

1. ☐ As all required additional search fees were timely paid by the applicant, this International Search Report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this International Search Report covers only those claims for which fees were paid, specifically claims Nos.:
4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this International Search Report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

- ☐ The additional search fees were accompanied by the applicant's protest.
- ☐ No protest accompanied the payment of additional search fees.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

Continuation of Box II.2

Claims Nos.: 13,14

Claims 13 and 14 do not recite any features.

The applicant's attention is drawn to the fact that claims, or parts of claims, relating to inventions in respect of which no international search report has been established need not be the subject of an international preliminary examination (Rule 66.1(e) PCT). The applicant is advised that the EPO policy when acting as an International Preliminary Examining Authority is normally not to carry out a preliminary examination on matter which has not been searched. This is the case irrespective of whether or not the claims are amended following receipt of the search report or during any Chapter II procedure.

INTERNATIONAL SEARCH REPORT

International Application No
PCT/GB2004/000117

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